ESRF	**Experiment title:** Characterization of mono- and poly-crystalline diamond detectors for hadron therapy and high energy physics applications	**Experiment number**: MI-1243
Beamline: ID21	**Date of experiment**: from: 17/05/2016 to: 21/05/2016	**Date of report**: 12/09/2016
Shifts: 9	**Local contact(s)**: Murielle Salomé	*Received at ESRF:*

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Summary :

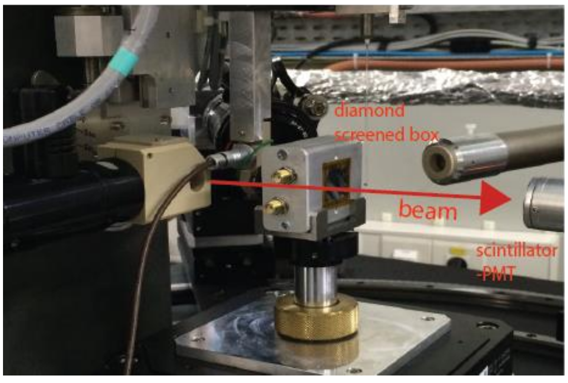
In the framework of two collaborations aimed at the development of high-energy particle detectors and hadron therapy monitoring, mono- and poly-crystalline diamond detectors and their frontend electronics have been characterized. As regards energy deposition in the diamond, in the ESRF 4-bunch mode, the ~100ps duration X-ray pulses that are spaced at 704ns intervals mimic the passage of single ionizing particles. We characterized the temporal and charge/current signal responses of several prototype diamond detectors over a large fraction of their surfaces with :

- sub-nanosecond timing using wide bandwidth (acquisition of pulse waveforms with digital sampling oscilloscopes (DSO) synchronized with the storage ring time structure.
- micron spatial resolution maps of the detectors, acquired using current integration acquisition in the fast ID21 'zapscan' mode.

This first experiment enabled us the refine the acquisition protocol for further characterizations that are necessary for the use of such detectors.

Experimental setup :

Diamond samples, with aluminium surface metallization, are mounted on sample holders with 50 Ω adapted impedance and SMA connectors, enabling reversible bias and signal readout from both sides of the diamond.. These samples are placed inside an electromagnetic shielding box: using a magnetic kinematic mount this is positioned with micrometric reproducibility at the target position of the micro-diffraction beam line (in air) of the ID21 side station. Figure 1 illustrates this sample setup. Additionally, a plastic scintillator was placed downstream, with readout by a photomultiplier tube (PMT). This was used for timing verification and detection efficiency comparison.



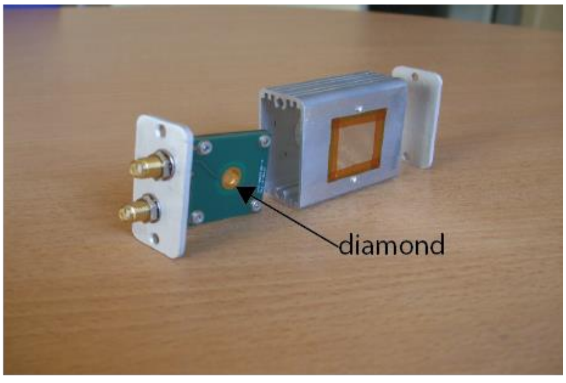


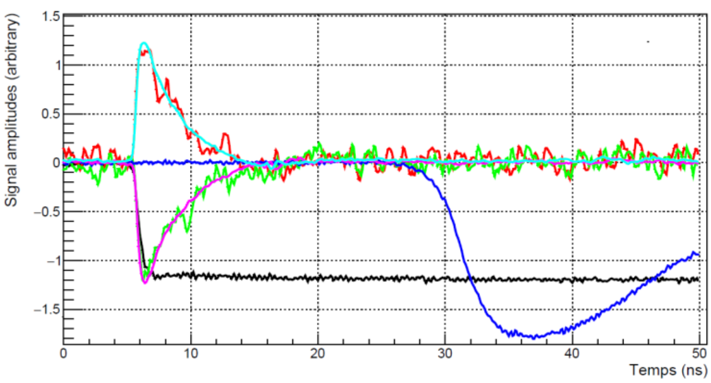
Figure 1: right: diamond detector mounting inside EM-shielding box. Left. Detector at the target position.

The pulse shape readout mode was performed alternatively with a 500 MHz, 3.2GS/s digital sampling 'Wavecatcher' system provided by the LPSC group, and with a 2 GHz, 20 GS/s analog bandwidth DSO (LeCroy 620Zi) provided by ESRF. This double configuration was useful since the Wavecatcher system could be configured in a continuous acquisition mode, recording all waveforms, and thus enabling large statistics offline analysis.
The acquisition of the DSO was fully integrated into the ID21 SPEC software acquisition framework which enabled us to measure the temporal response of the detectors as they were motor scanned in the beam, thus creating 3D maps (x,y position and response time). Both acquisition systems were trigger-synchronized by the RF of rhe ESRF synchrotron, itself integer divided down by an ESRF BCDU8 timing module.
The 100msec current integration readout mode was performed by means of a Keithley 485 electrometer coupled to a voltage to frequency converter and a standard ID21 counter.
Several preamplifiers were tested: the CIVIDEC C2 low noise broadband RF amplifier (2 GHz, 40 dB from CIVIDEC Instrumentation company[1]); DBA III (Diamond Broadband Amplifier) from GSI (a similar 2 GHz design with a gain remotely controlled from 0 dB to 38 dB) and a low cost current preamplifier designed at LPSC (1 GHz, 30 dB still under design). These Amplifiers are intended for use with fast detectors. They exhibit a 50 ohms input impedance and are able to work with FWHM pulse widths of less than 1 ns.
Four synthetic CVD grown diamond detectors were tested: one single crystal and two polycrystalline from the manufacturer Element 6, and one diamond grown heteroepitaxially at Augsburg University.

<u>Results:</u>

1/ Efficiency: The ID21 beam was attenuated, varying the intensity on the detector-target from a maximum of 1400 photons/bunch to a minimum of less than 1 photon/bunch. The photon energy was fixed at 8.5 keV. Therefore, the absorbed energy in the diamond detectors ranged from ~6 MeV to ~zero per pulse.
The average pulse height and average pulse shape were measured several points of each detector, with a variation of the beam intensity, and variation of the detector bias (-500V to +500V). This part of the data analysis is still in progress.

2/ Pulse shape analysis: Figure 2 shows a typical screenshot of the DSO, where two diamond signals are represented (one from each side of the detector), and the signal from the plastic scintillator-PMT. This illustrates nicely the rapidity of the diamond response compared to the photomultipliers signals. The diamond rise time is less than 1ns, whereas the plastic+PM signal rise time is about 6 ns.



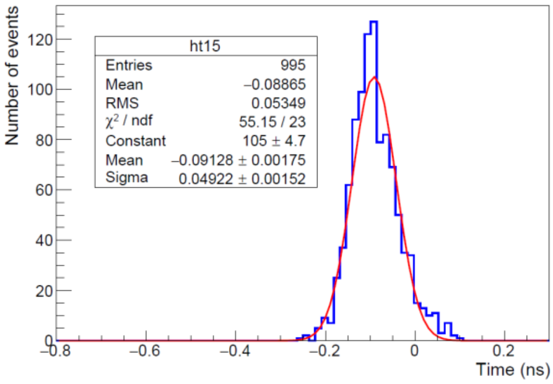


Figure 2 (left): Signal rise times (green and red traces) for a diamond detector, the two opposite signals arising from both sides of the detector. The light blue and mauve traces are the 64-fold signals averaged by the DSO. The dark blue trace is the signal from the plastic-scintillator coupled to photomultiplier, and the black trace is the trigger signal from the BCDU8 unit. Figure 3 (right): Numerically calculated CFD time jitter between the two independent readouts of a diamond detector.

An offline procedure was established to determine the time resolution of the detectors. The averaged readout signal waveforms are recorded independently on both faces of a detector. A numerical Constant Fraction Discrimination (CFD) was used by averaging the background, determining the maximum of the pulses, and interpolating the 50% rise time value. The distribution of the time difference between two faces of a detector is characteristic of the readout chain jitter. Figure 3 represents such a distribution for a 300µm thick, 5×5 mm^2 polycrystalline detector. In the present case the resolution is 49ps rms (to be divided by 1.414 for a

[1] https://cividec.at/index.php?module=public.product_show&id=15&cat=0

single signal since this is an auto-convolution). The summary for several detectors and several preamplifiers, is given in Table 1.

	Size (provider)	Preamps.	HV (V)	Amplitude (mV)	Noise rms (mV)	Signal to Noise Ratio	Timing resolution (rms) between two-side signals (ps)
Mono-crystalline Diamond	**0.45 x 0.45 cm² x 518 µm (E6)**	Cividec	-500	134.3	2.812	47.76	26.7
			500	148.2	2.229	66.48	25.1
		DBAIII	-500	54.63	2.02	27.04	48.84
			500	52.76	1.987	26.55	50.11
		LPSC	-500	126.5	3.312	38.19	53.8
			500	167.1	4.005	41.72	48.41
Poly-crystalline Diamonds	**0.5 x 0.5 cm² x 300 µm (A)**	Cividec	300	-56.98	2.863	19.9	49.22
	10 x10 cm² x 500 µm (E6)	Cividec	300	-55.74	2.64	21.11	71.94
	10 x 10 cm² x 500 µm (E6)	Cividec	300	-55.91	3.569	15.66	79.22

Table 1: Summary of average amplitude, signal to background ratio and timing resolution for 4 different diamond detectors and 3 different preamps. E6: Element 6 diamonds, A: Augsburg heteroepitaxic diamond

3/ Surface mapping: Surface mapping of several detectors was performed. Figure 4 shows an example of a polycrystalline detector map (4 cm^2 detector from Element 6). The colour scale corresponds to the charge collection efficiency measured by an electrometer. Clearly, the response of the detector reflects the spatial distribution of grain boundaries in the polycrystalline material. The case presented here corresponds to the worst variations measured, chosen as the image shows good contrasts! In addition, the simultaneous map created by the ID21 upstream beam intensity monitor showed high signal areas corresponding intensity losses by the diamond detector, resulting from the occasional Bragg backscattering from the randomly oriented crystallites in the polycrystalline diamond. The heteroepitaxially grown, diamond on Iridium, sample from the Augsburg University laboratory exhibited a much more homogeneous response.

Figure 3: surface map of a small area (220 µm × 230 µm) of a polycrystalline diamond detector showing intensity variations corresponding to the grain distribution in a polycrystalline Element 6 sample.

Scientific production and perspectives :

The results will be presented at the international conference IEEE-NSS-MIC in November 2016 (accepted contribution), as well as the yearly ADAMAS workshop on diamond detectors. We foresee a publication in the corresponding IEEE-TNS journal by the end 2016-begining 2017.

We are now considering further development of large area detectors provided by Augsburg Univ. with appropriate strip metalization. Also, we will better optimize detector thickness. Further measurements are necessary, and are the subject of a new proposal.